The next ten years: chaos or illumination

Pier Oddone, Fermilab

Brookhaven Forum 2010
May 28, 2010

Hold on to your seats……..

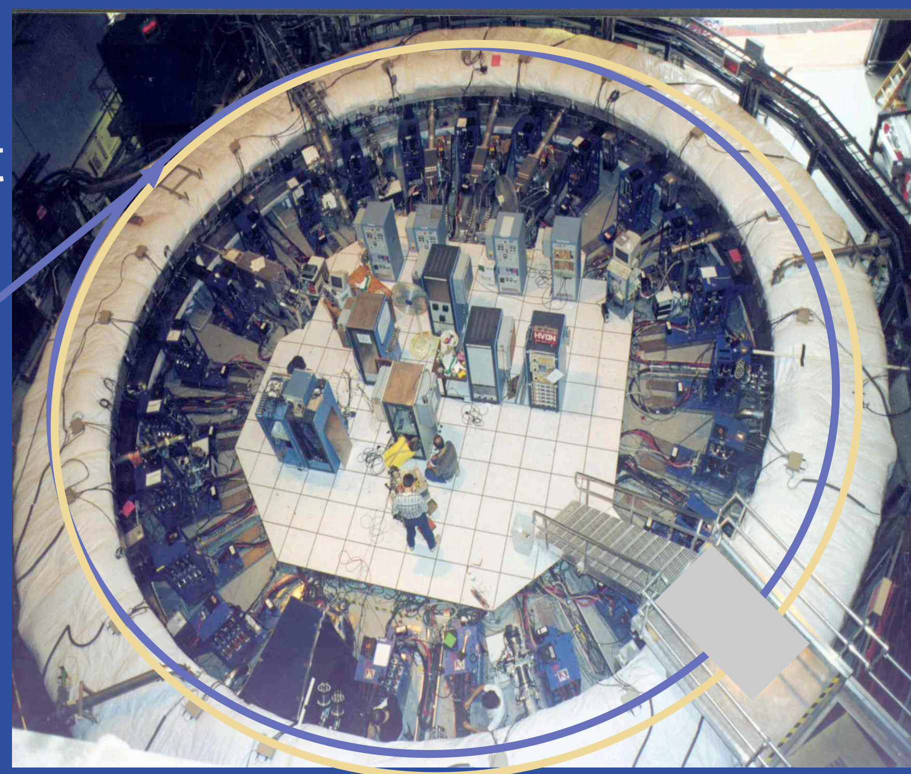
- The next decade is here! The greatest expectations in generations and the greatest uncertainties....
- As we have heard in BF2010: any number of models are possible – few clues from present experiments.
- The LHC will be the dominant tool – but critical questions remain in other areas: for neutrinos, rare processes, dark matter and dark energy

New physics: what clues do we have?

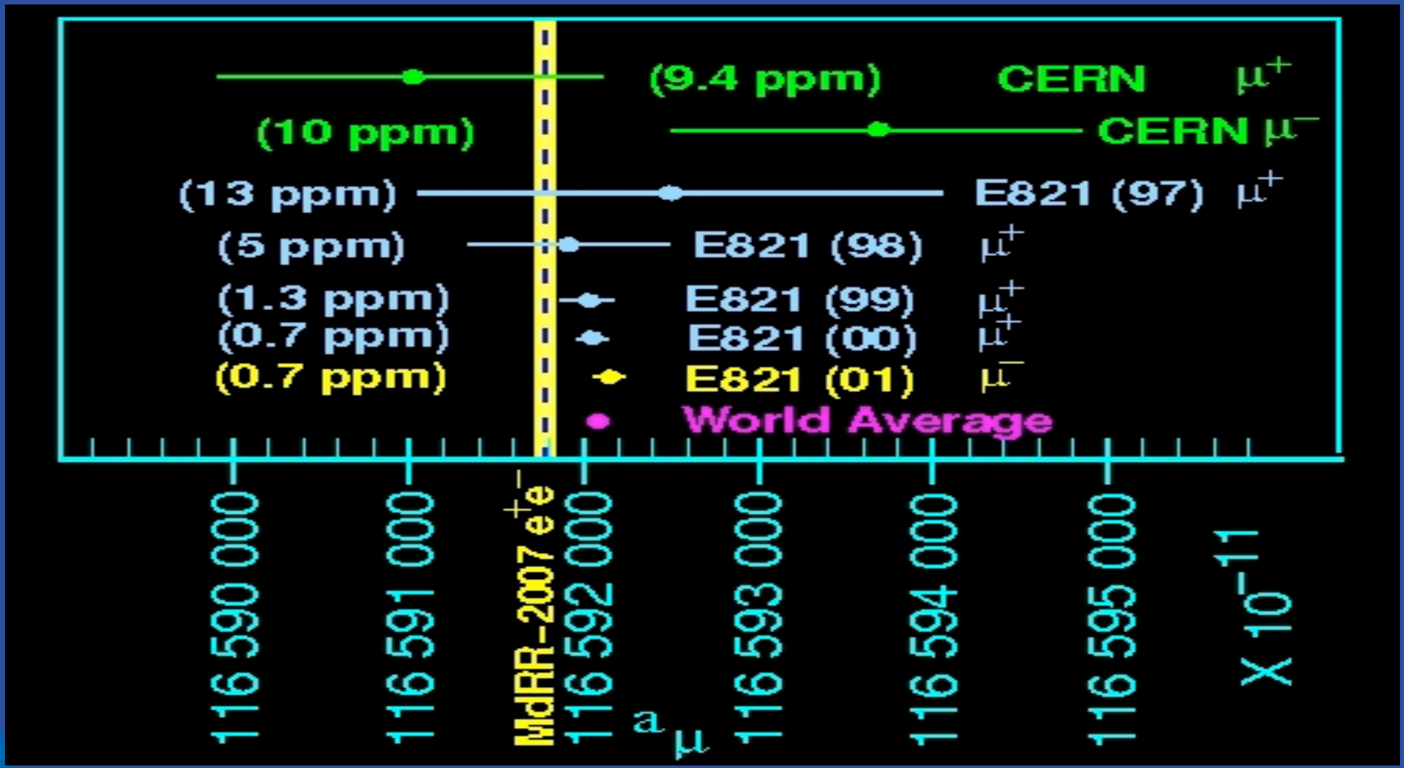
- The biggies:
  - Dark matter
  - Dark energy
  - Neutrino masses
  - Matter antimatter asymmetry in the universe
  - Three flavors
  - Unitarity at TeV scale?
- But is the new physics around the corner? Looking through precision tests…….

What clues do we have?

- G-2: anomalous magnetic moment of the muon shows a 3 sigma deviation from SM predictions



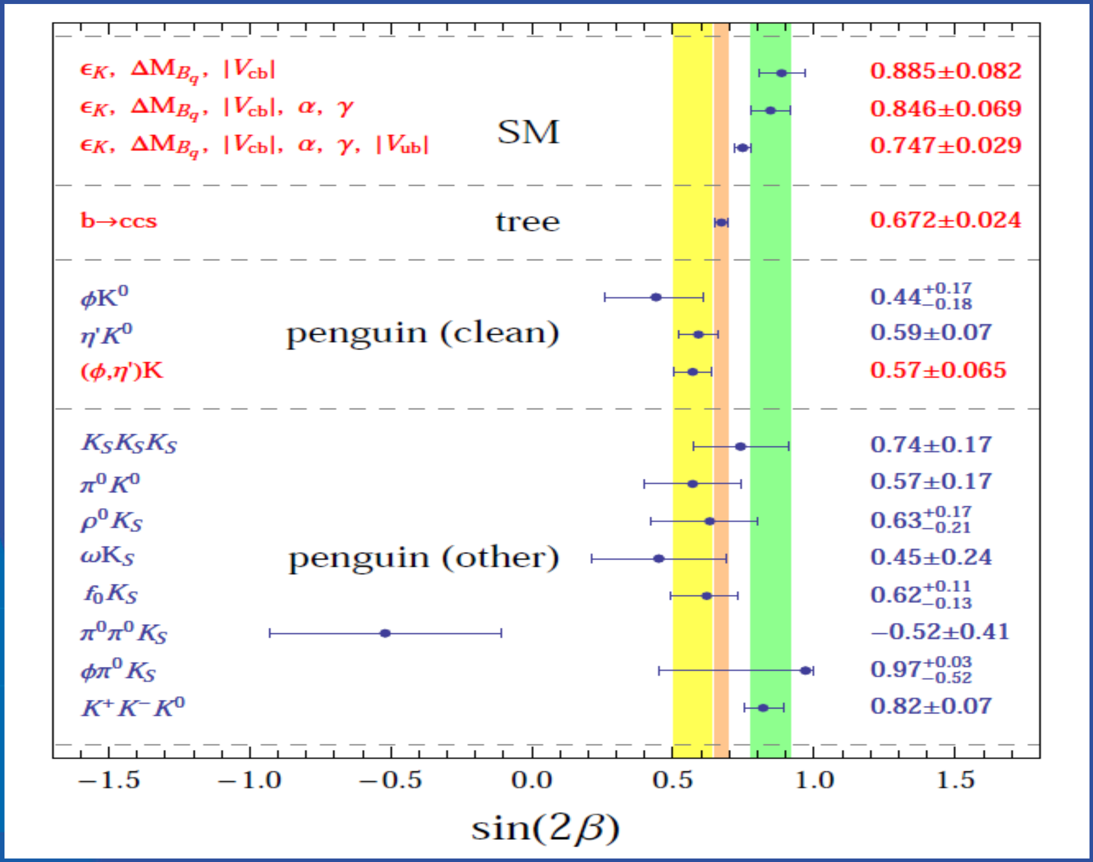
What clues do we have?



$$\Delta a_\mu \equiv a_\mu^{exp} - a_\mu^{SM} = (255 \pm 80) \times 10^{-11}$$

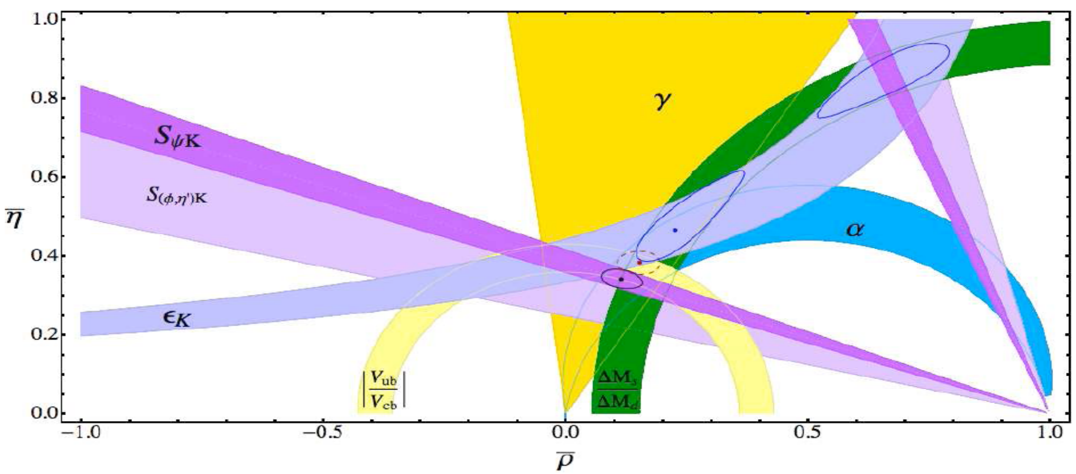
What clues do we have?

Tension in comparison of different determinations of sin (2β) (See Neubert at BF2010)



What clues do we have?

Tensions in fitting unitarity triangle

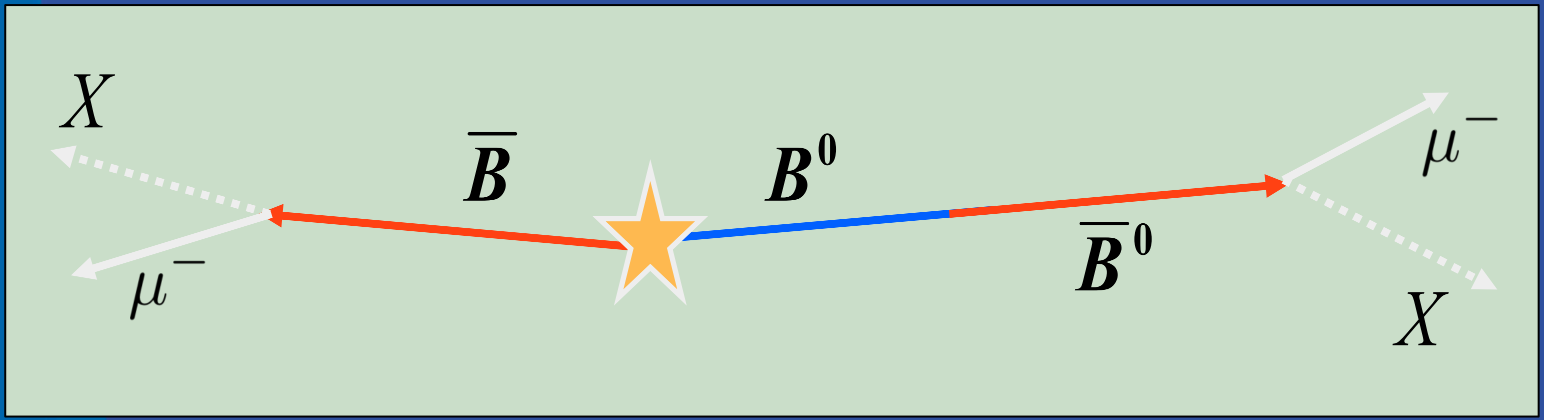


mode	w/out V_{ub}	with V_{ub}
$S_{\psi K_S}$	$2.4\ \sigma$	$2.0\ \sigma$
$S_{\phi K_S}$	$2.2\ \sigma$	$1.8\ \sigma$
$S_{\eta' K_S}$	$2.6\ \sigma$	$2.1\ \sigma$
$S_{(\phi+\eta')K_S}$	$2.9\ \sigma$	$2.5\ \sigma$

Lunghi and Soni, PL B666 (2008) 162

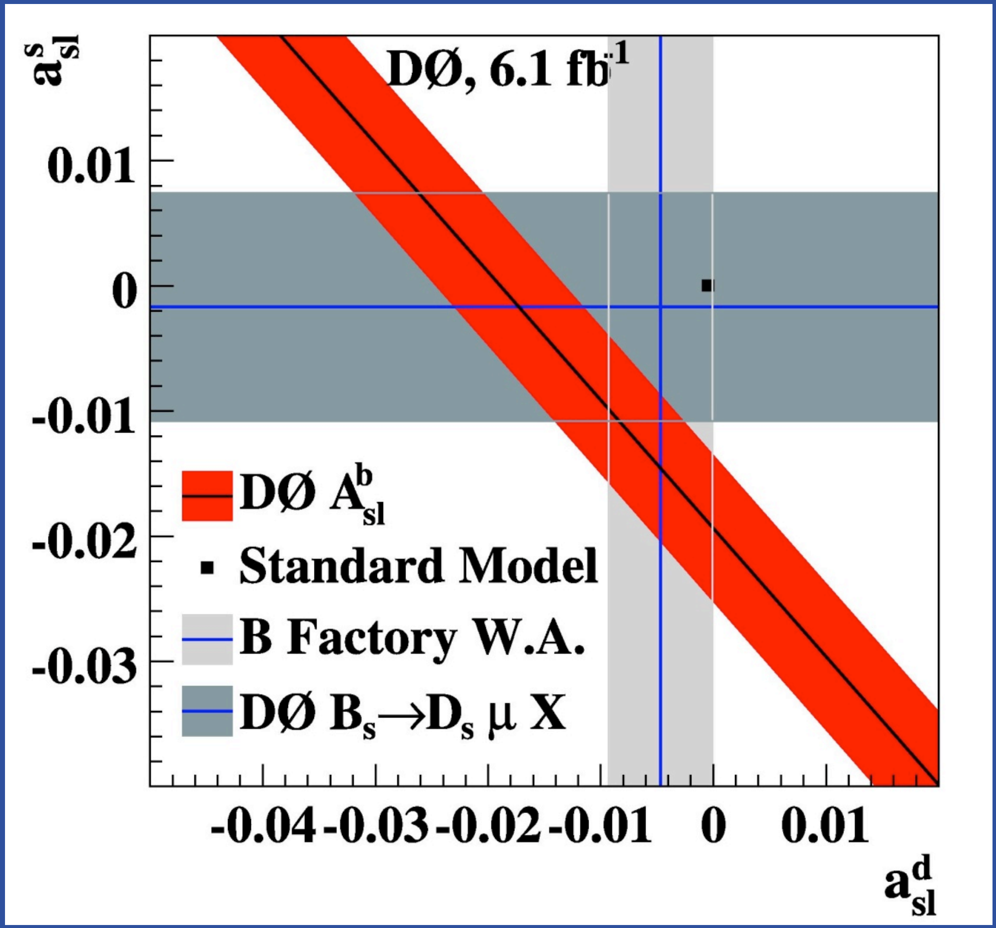
What clues do we have?

- Recent measurement of di-muon asymmetry in DZERO



$$A_{sl}^b \equiv \frac{N_b^{++} - N_b^{--}}{N_b^{++} + N_b^{--}}$$

What clues do we have?

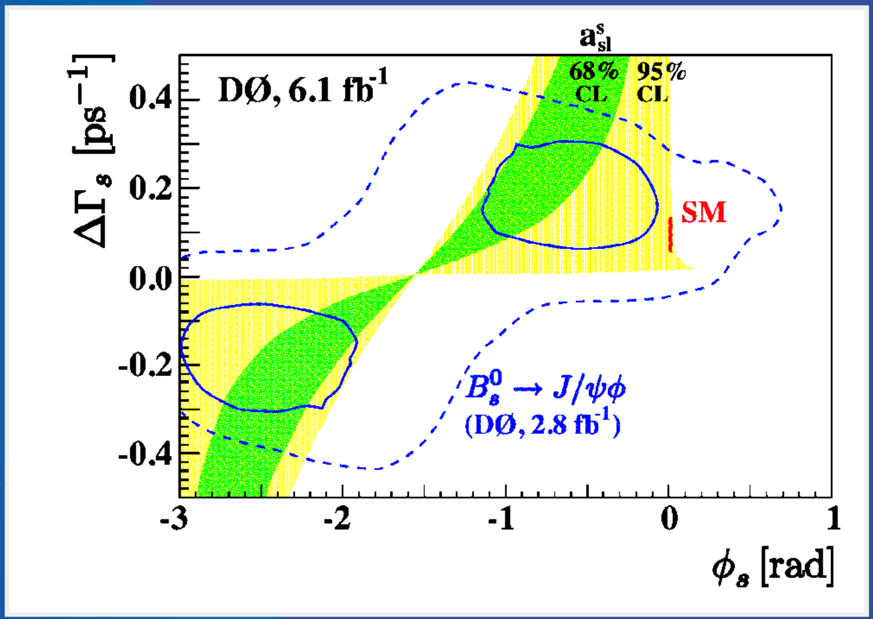


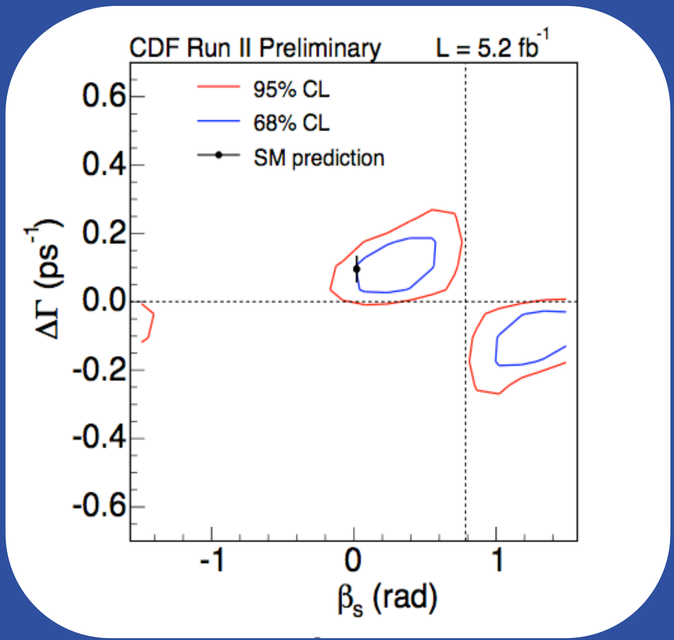
New at BF2010, Tonelli, Tsybychev

$$A_{sl}^{b} = 0.506\, a_{sl}^{d} + 0.494\, a_{sl}^{s}$$

What clues do we have?

Further evidence from independent measurements of ϕ_s and $\Delta\Gamma_s$ in $B_s \rightarrow J/\psi\phi$ decay (Tonelli, Tsybychev @BF2010)

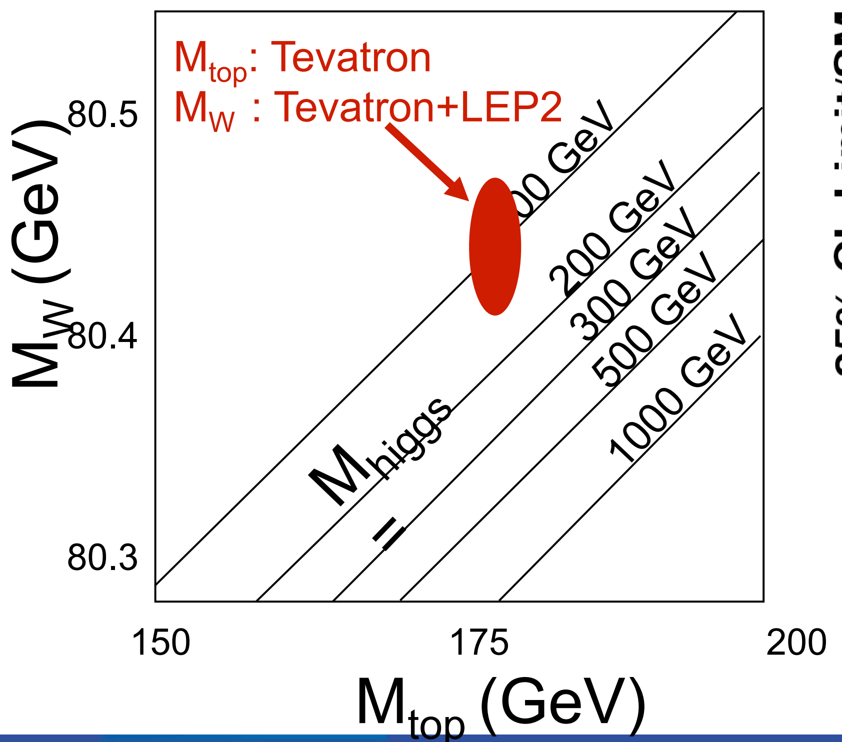




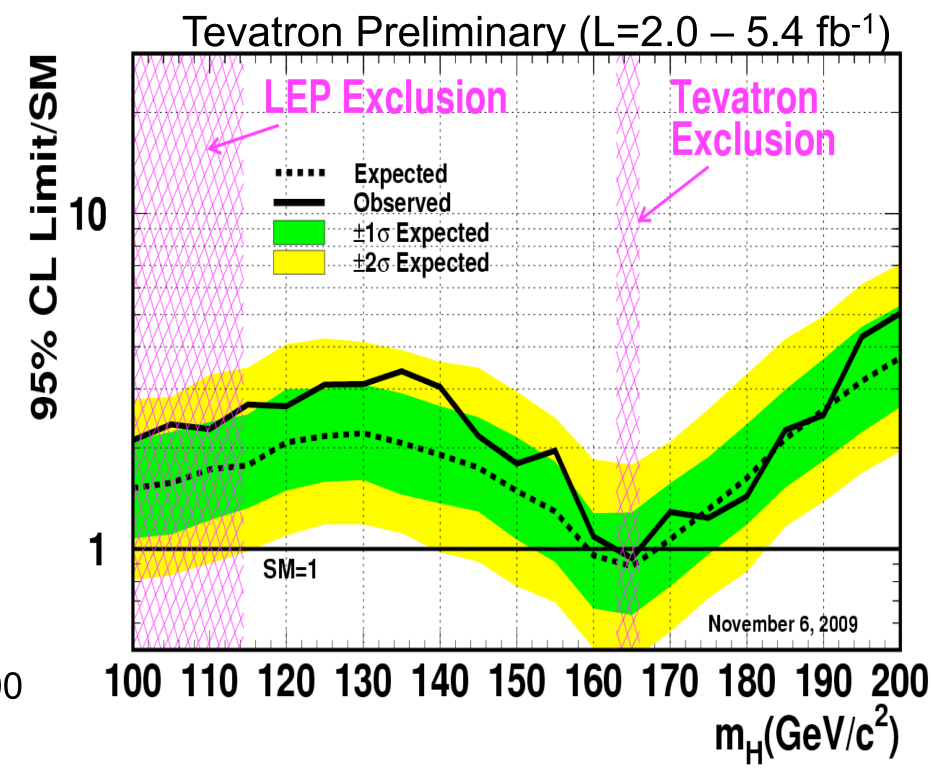
What clues do we have?

Electroweak fits

Predict Higgs Mass



Search for Higgs



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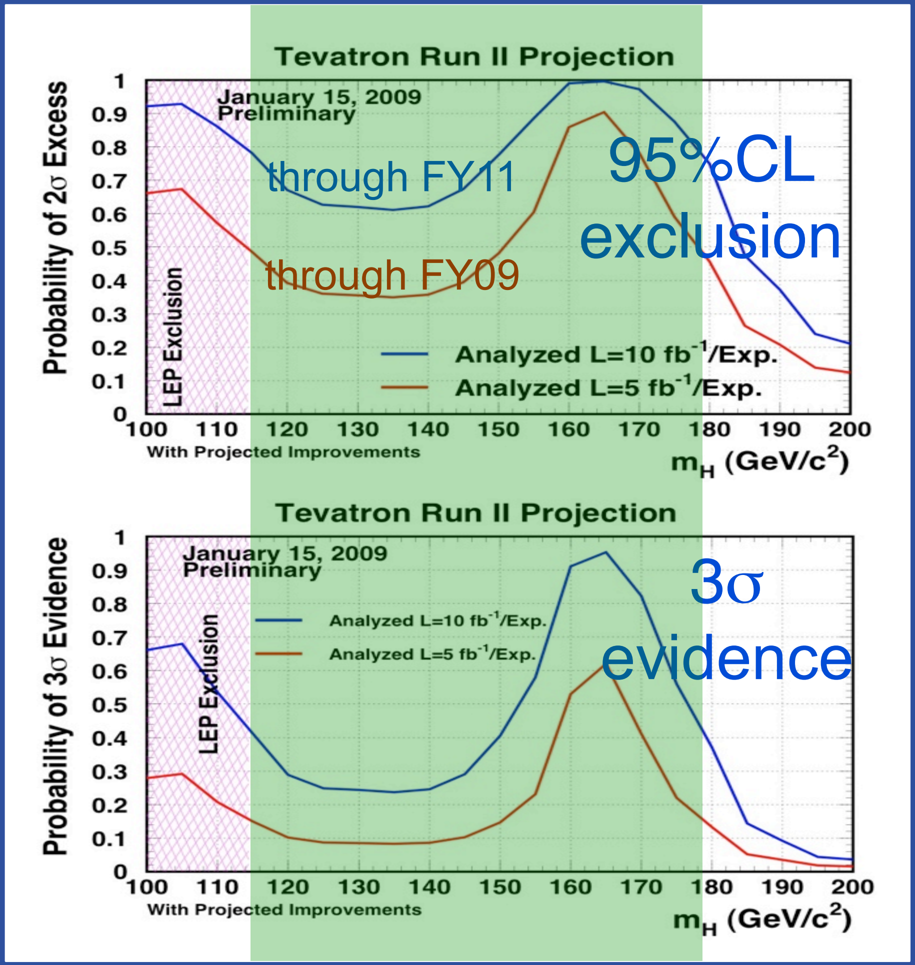
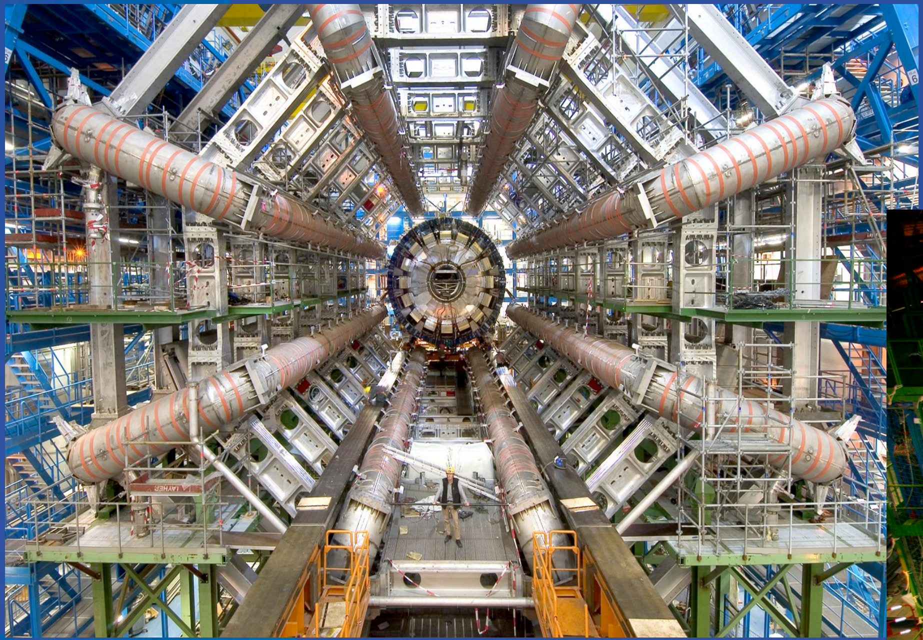
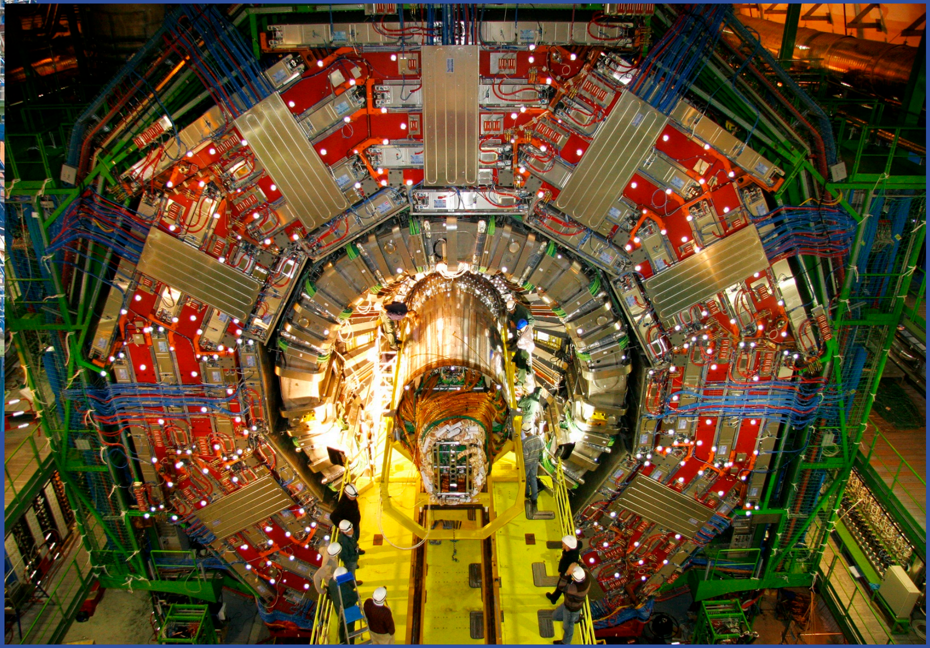
Is there more juice in the Tevatron?



Energy frontier will move to the LHC

Powerful detectors



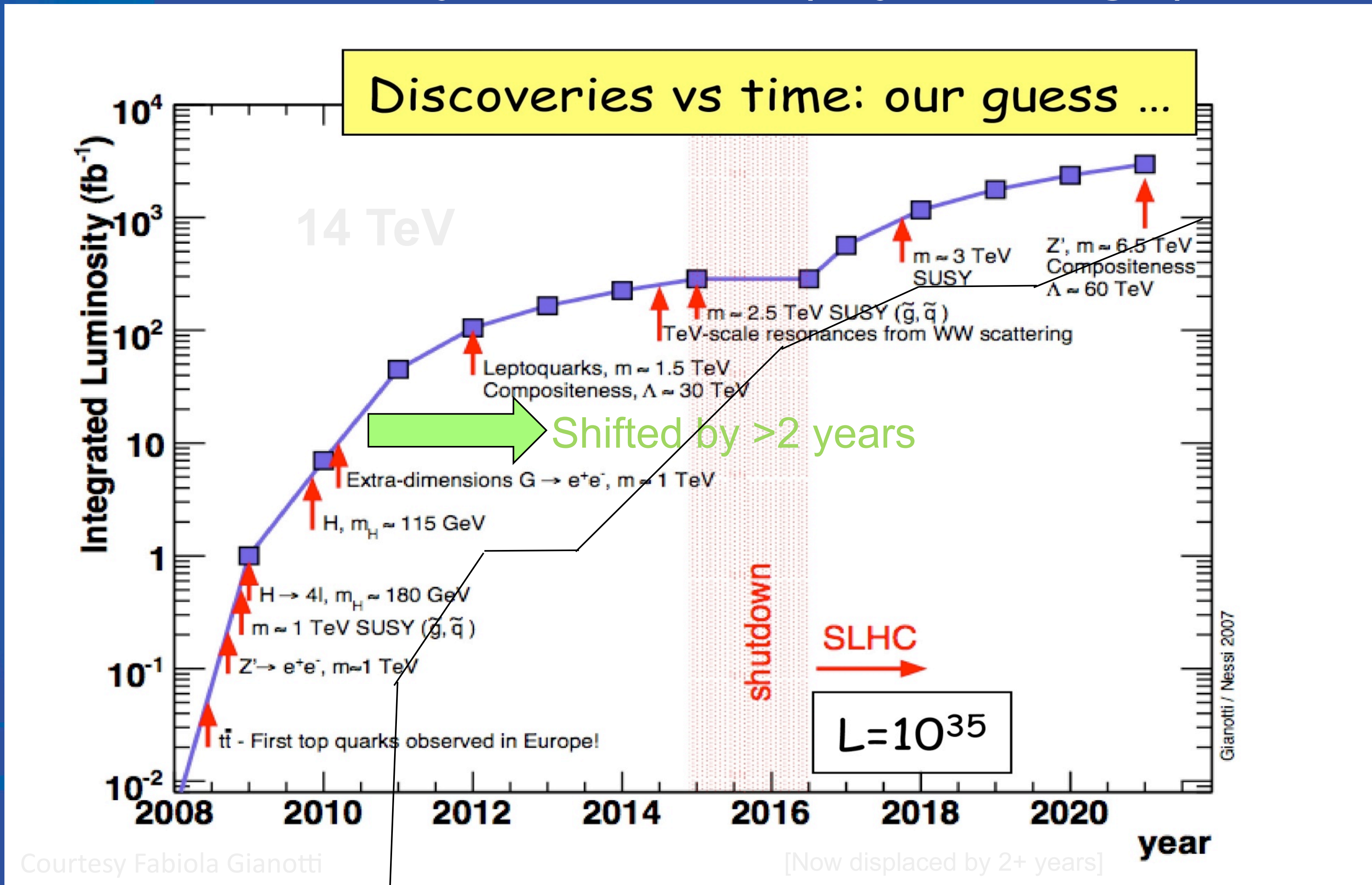


(See Erbacher and Heinemann at BF2010)

Huge physics reach

- Theorists have imagined a veritable Jurassic Park of possibilities in this new energy range:
  - Minimal Supersymmetric (MSSM)
  - Many other models of supersymmetry (less predictive)
  - New Z’ similar to the Z boson, but higher masses
  - Extra dimensions and Kalusa-Klein towers
  - Technicolor
  - Lepto-quarks
  - Mini black holes
  - ……………………..

LHC physics reach (3 years ago)



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Detectors are fantastic!

- Physics will come quickly: weeks to months after data taking
- Also means many effects will appear first at the 3 sigma level so we will be chasing many things on the way to discovery
- When will we be able to be confident enough to say what the next machine is?
- Great confusion? (See Lykken at BF2010)

Biggest decision of the decade !

LHC Results

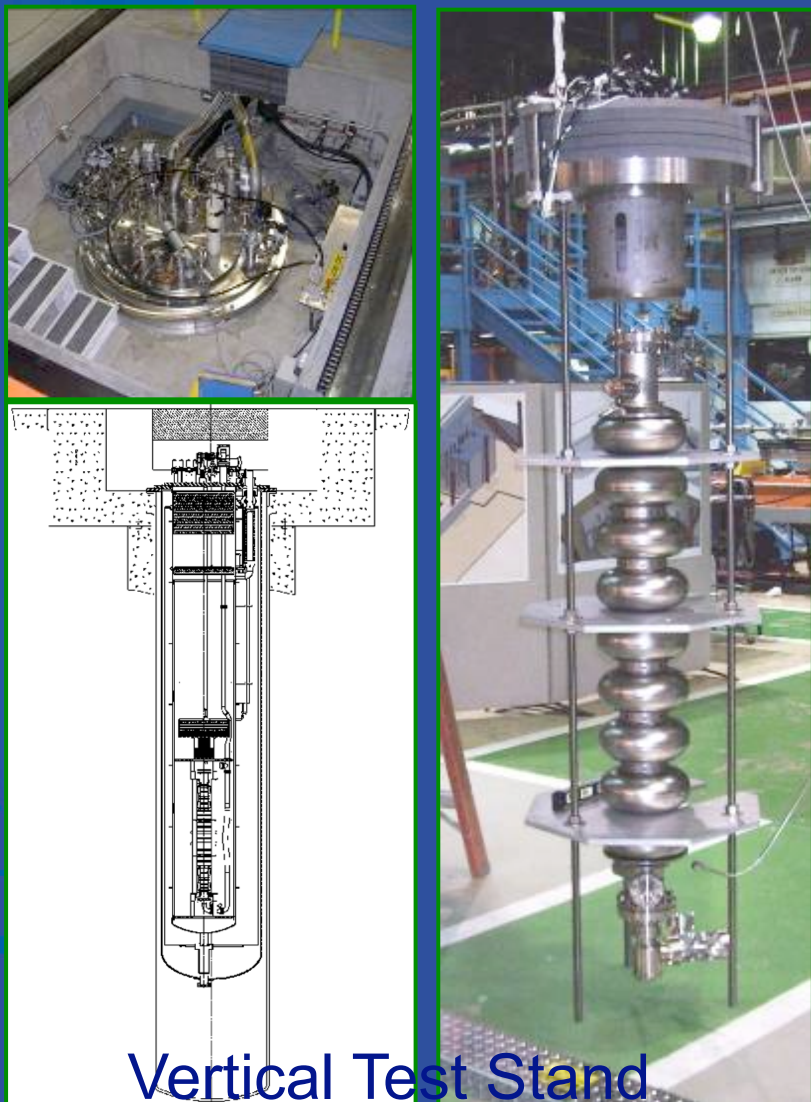
or

- ILC Enough → By far the easiest! A Global program
- ILC not enough

  or

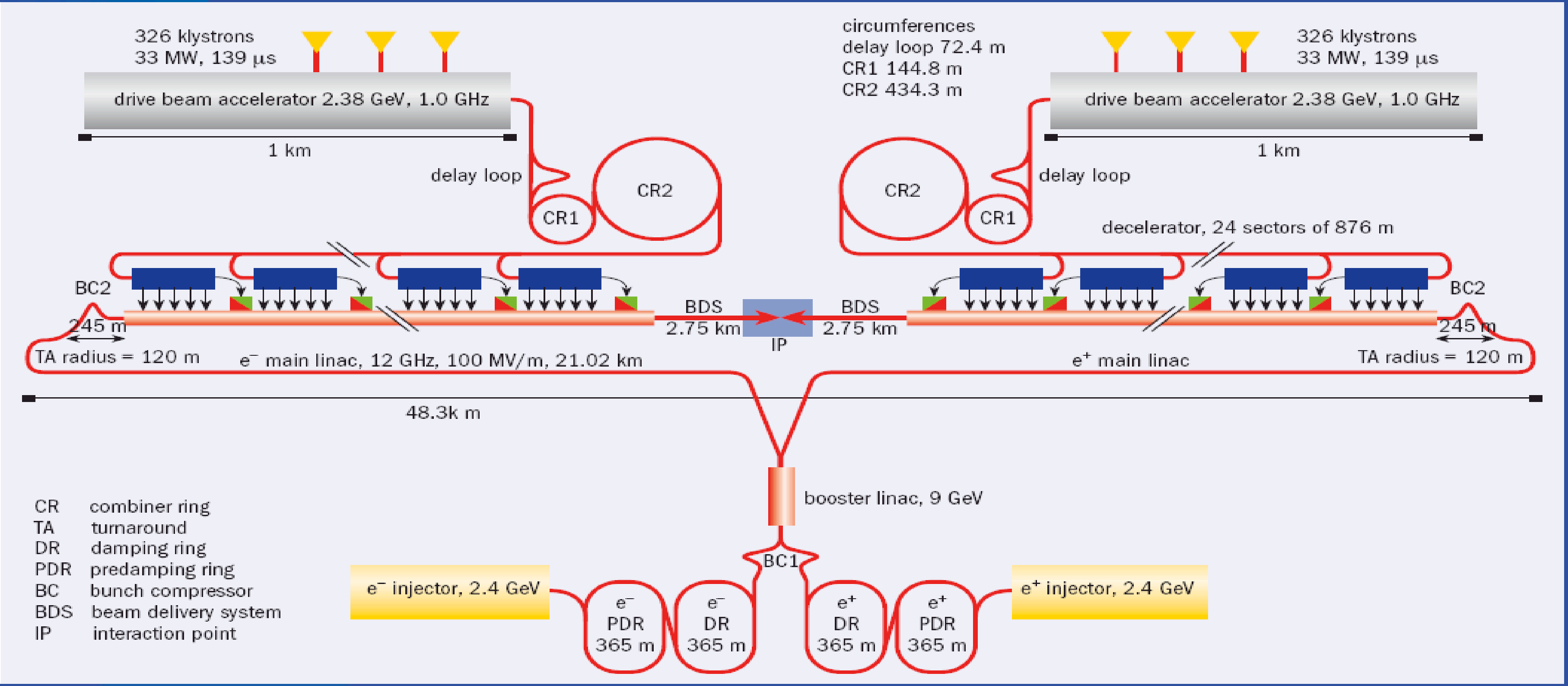
  - CLIC
  - Muon collider

ILC/Project X/XFEL technology



If we need higher energies…..

- If the energy of the ILC is too small (0.5 TeV or a little higher) we will need another approach: CLIC or muon collider



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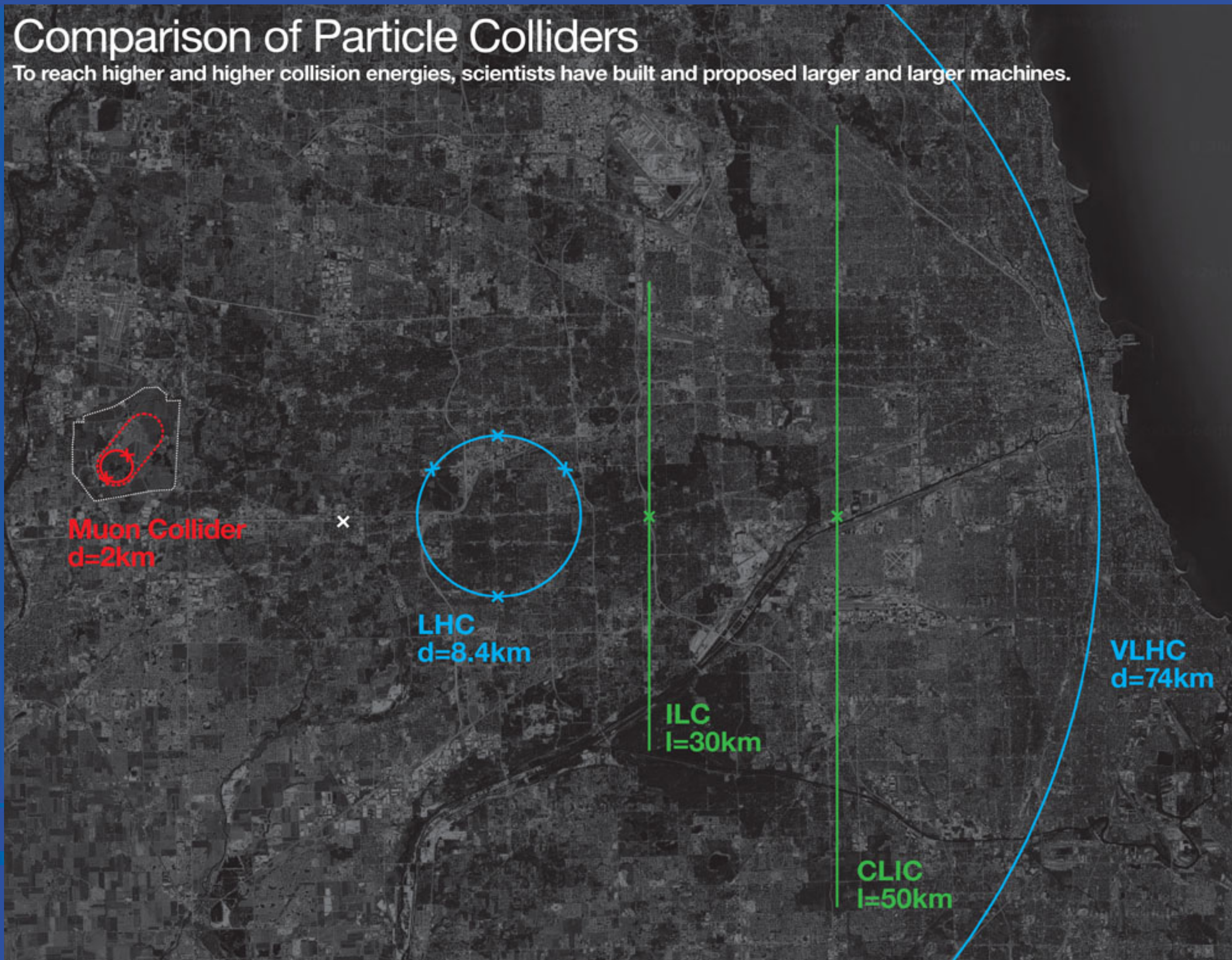
Muon Collider approach

- If the energy of the ILC is too small (0.5 TeV or a little higher) we will need another approach: CLIC or muon collider
- Collider based on a secondary beam: we have experience basing colliders on antiprotons. For muons we must do it in 20 msec.
- The biggest advantages are: narrow energy spread (no beamstrahlung) and small physical footprint (no synchrotron radiation
- DOE OHEP has asked Fermilab to organized the national R&D program


Comparison of Particle Colliders
To reach higher and higher collision energies, scientists have built and proposed larger and larger machines.
Muon Collider
d=2km
LHC
d=8.4km
ILC
l=30km
CLIC
l=50km
VLHC
d=74km

Muon Collider Conceptual Layout

Project X
Accelerate hydrogen ions to 8 GeV using SRF technology.

Compressor Ring
Reduce size of beam.

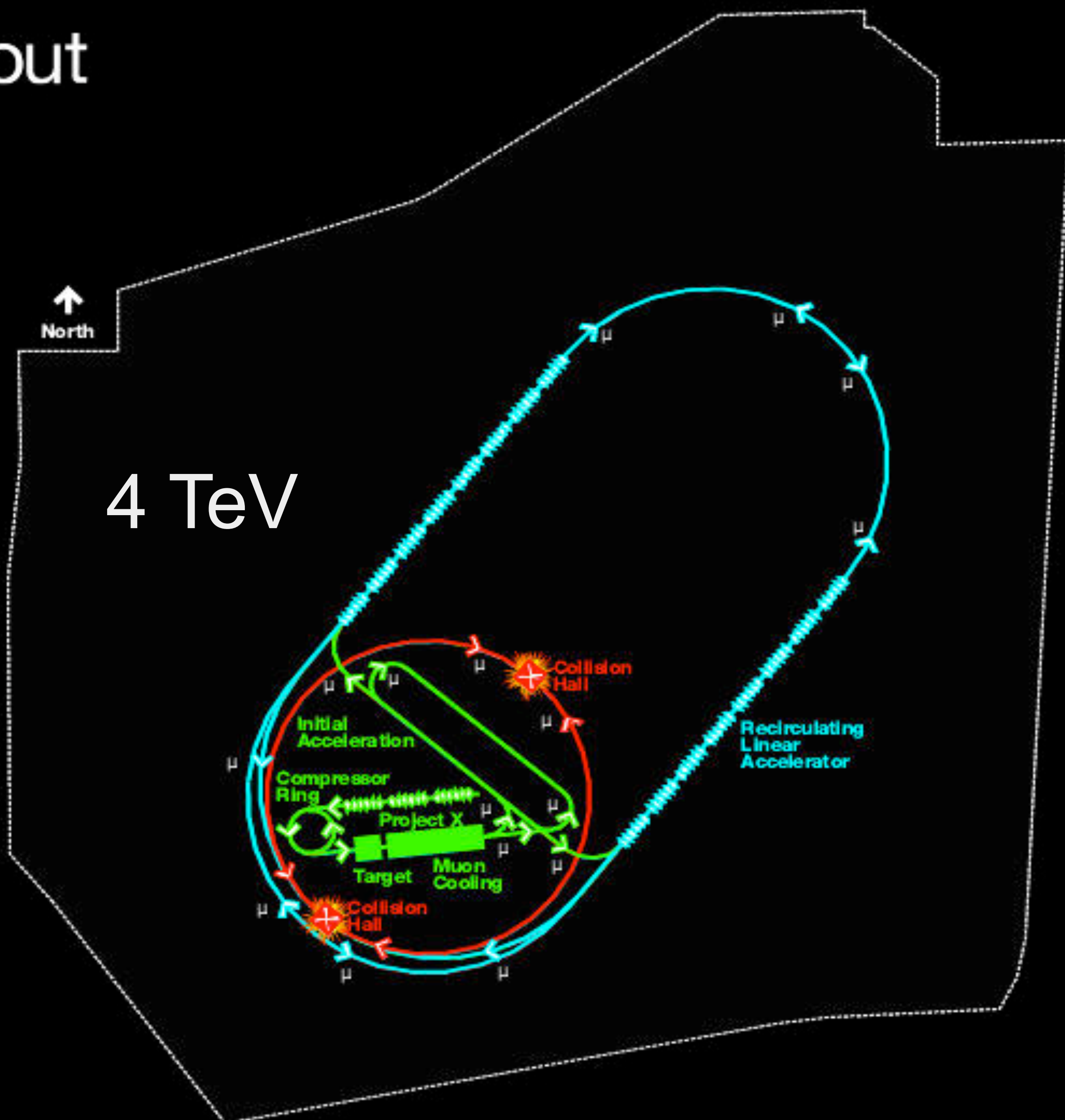
Target
Collisions lead to muons with energy of about 200 MeV.

Muon Cooling
Reduce the transverse motion of the muons and create a tight beam.

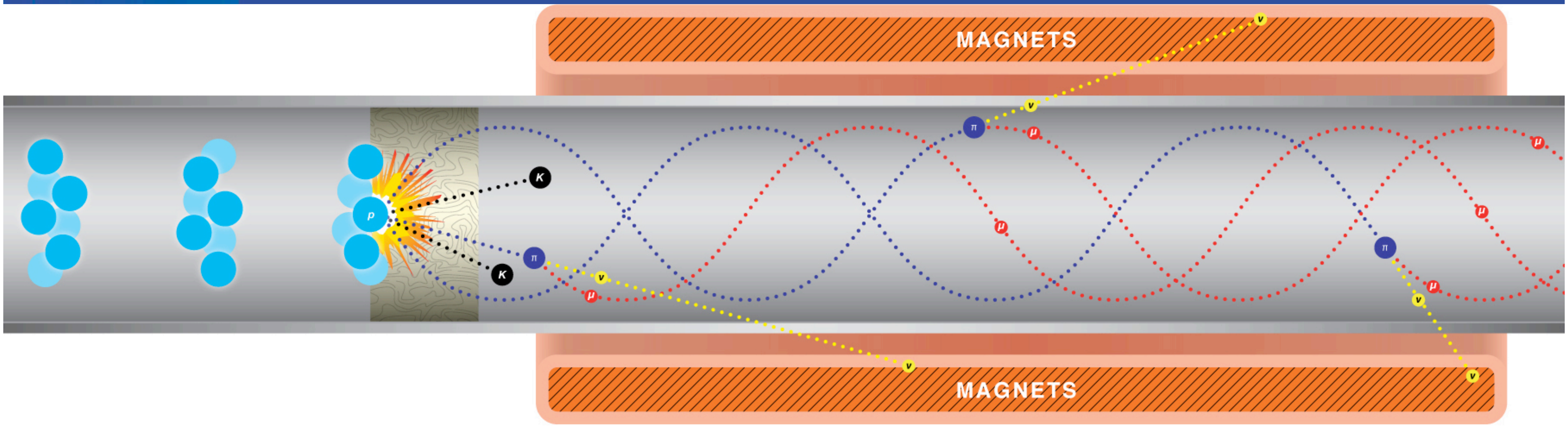
Initial Acceleration
In a dozen turns, accelerate muons to 20 GeV.

Recirculating Linear Accelerator
In a number of turns, accelerate muons up to 2 TeV using SRF technology.

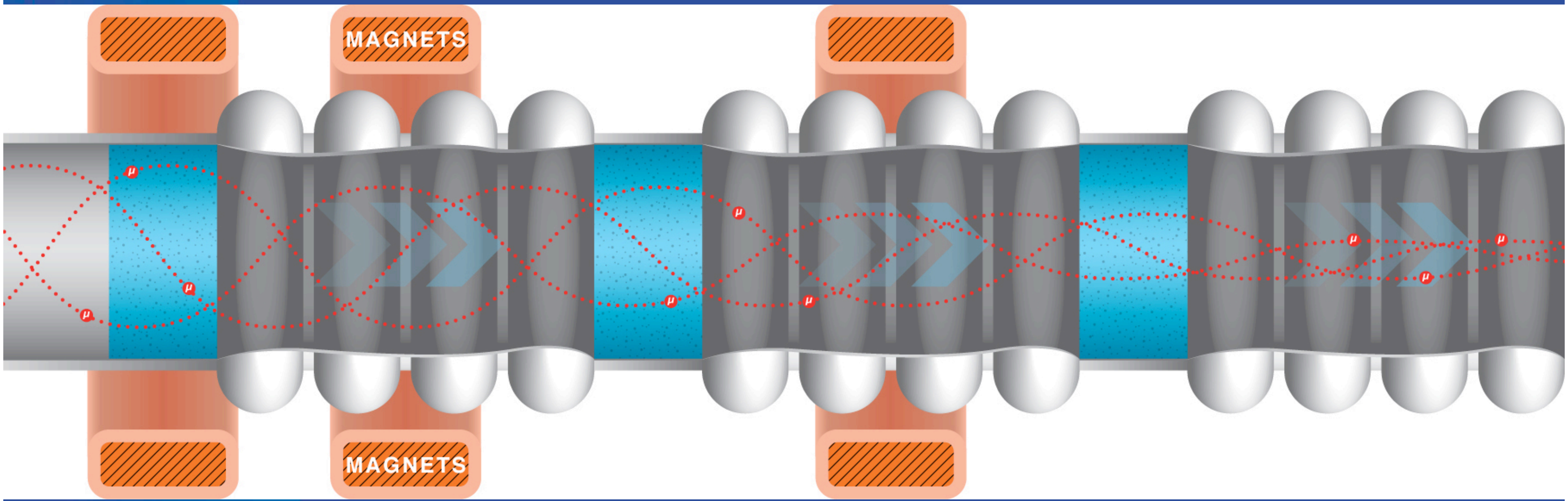
Collider Ring
Located 100 meters underground. Muons live long enough to make about 1000 turns.



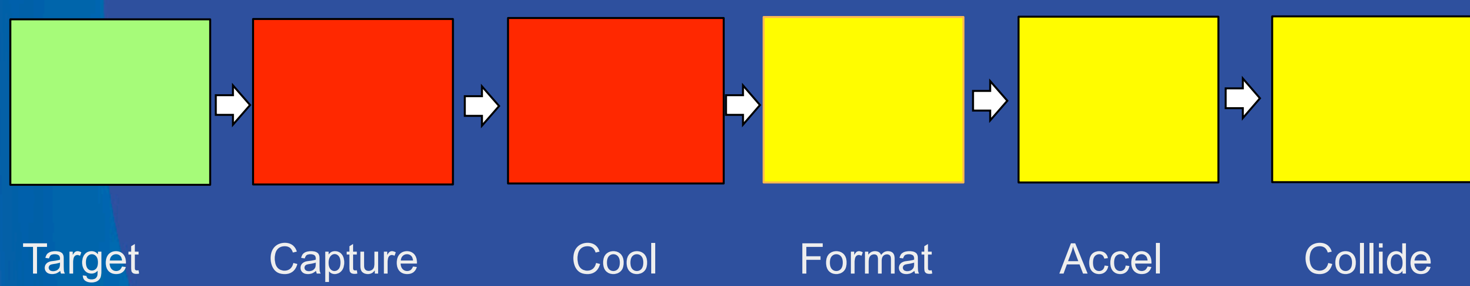
Targeting and capturing



Capturing and cooling



Muon collider functional layout



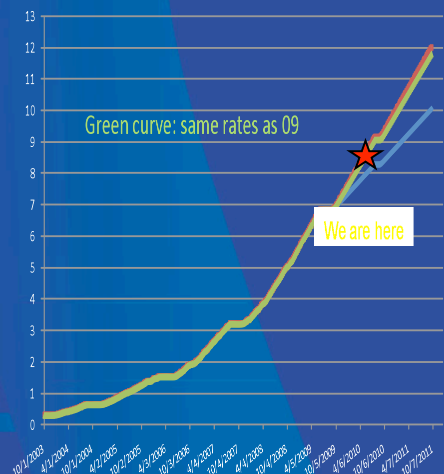
Color indicates degree of needed R&D (difficulty) and demonstration

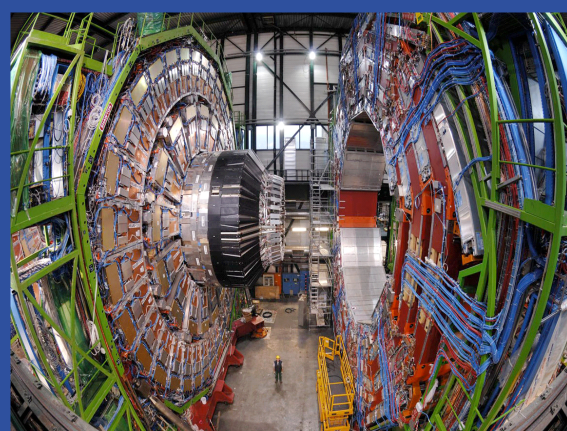
The energy frontier

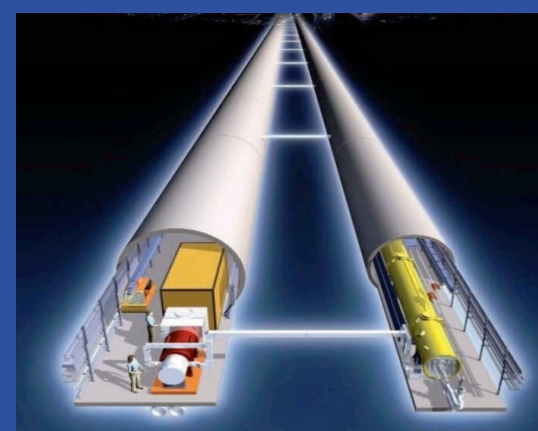
Energy

Tevatron LHC	LHC LHC upgrades	LHC ILC?	LHC CLIC or Muon Collider?

Now 2012 2015 2018







Interplay: LHC ⟷ Intensity Frontier

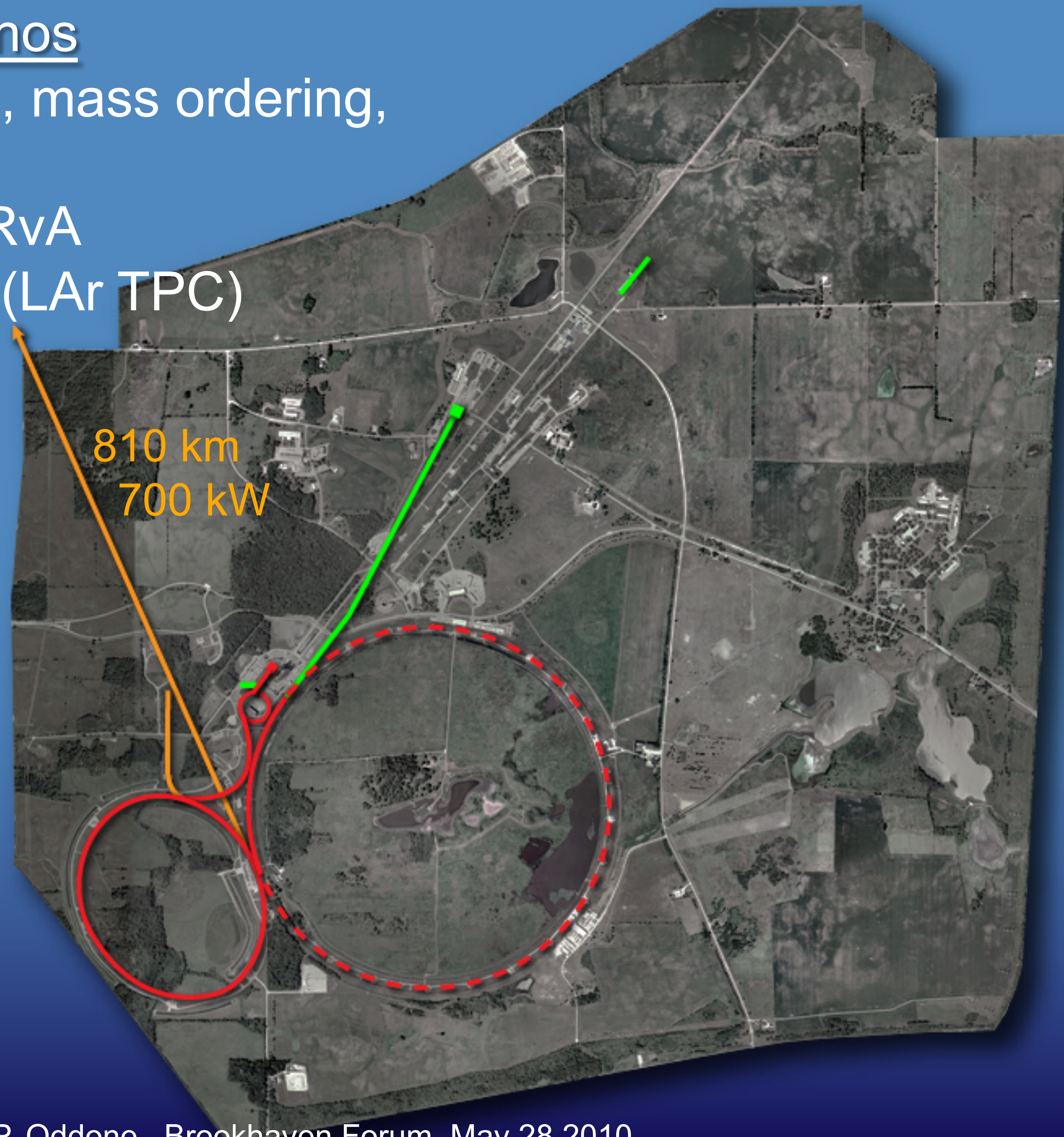
LHC	Intensity Frontier
nothing →	Only handle on the next energy scale
LHC	Intensity Frontier
Lots ⟷	Determine/verify structure of new physics. Anything beyond?

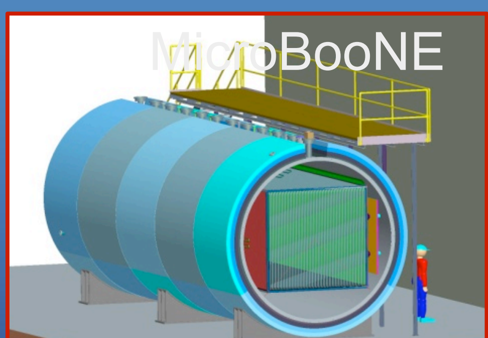
Intensity is key for neutrinos

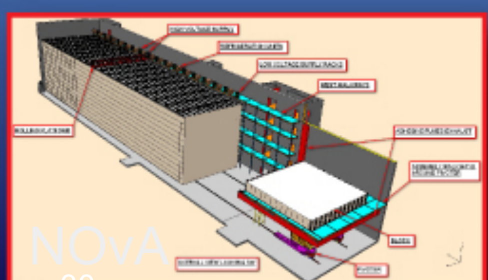
- Only weak interactions: very small cross sections >> hard to study
- Need large flux of particles and massive detectors
- Complementary to LHC: measure neutrino parameters (new symmetries?), neutrino masses, matter-antimatter symmetry violation and surprises.
- This route like the energy path depends of what we find in the current generation of experiments

Neutrinos

NOvA (off-axis): θ_{13}, mass ordering,
....
MINERvA
MicroBooNE (LAr TPC)





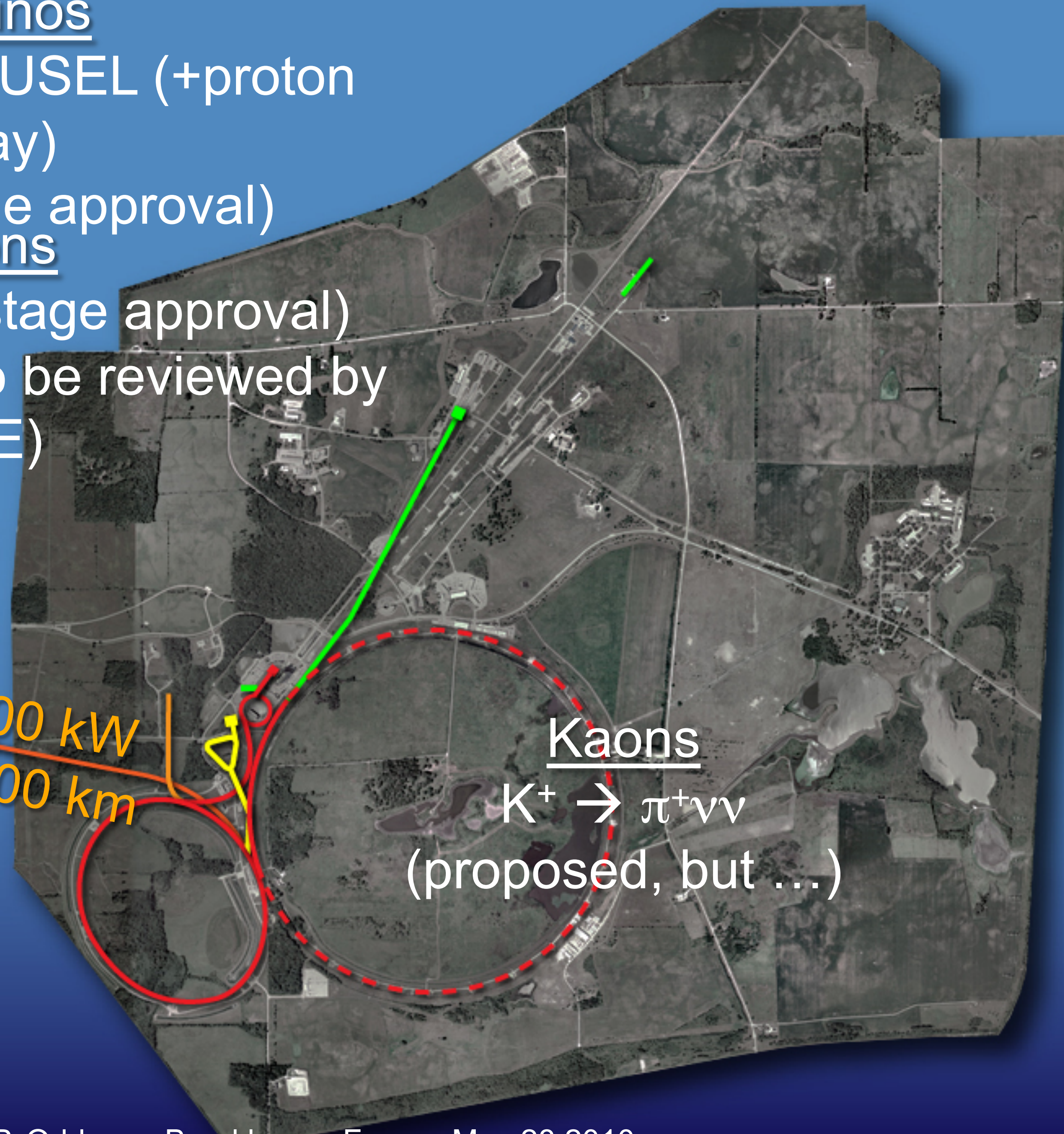


Neutrinos

LBNE: FNAL→DUSEL (+proton decay)
(DOE 1st stage approval)

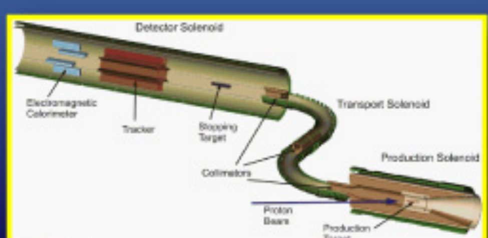
Muons

Mu2e (DOE 1st stage approval)
Muon g-2/EDM (to be reviewed by DOE)



Kaons

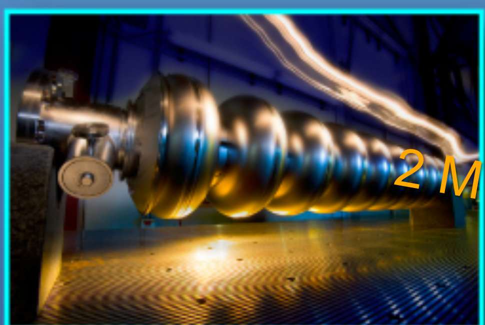
$K^+ \rightarrow \pi^+\nu\nu$
(proposed, but …)

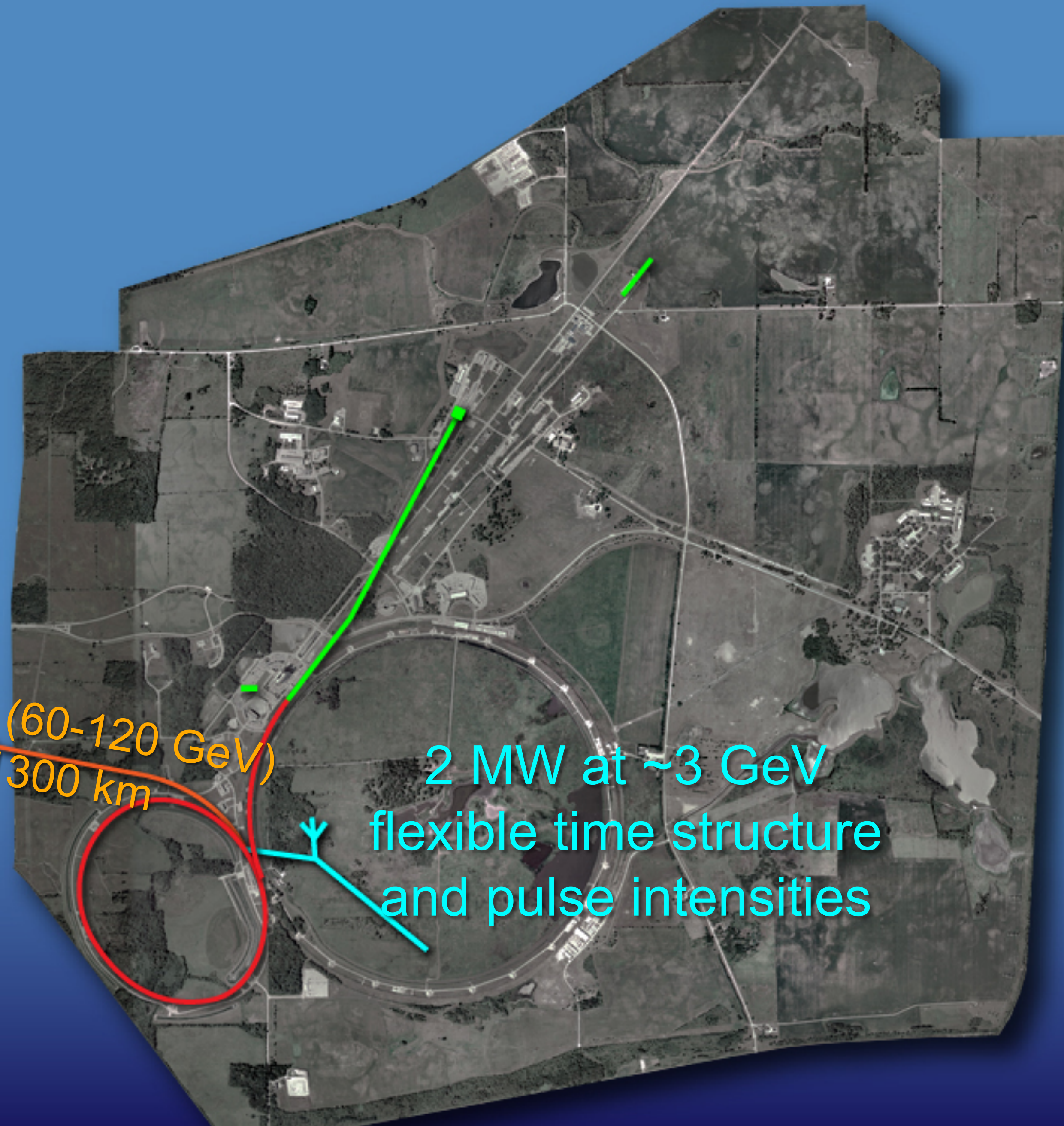


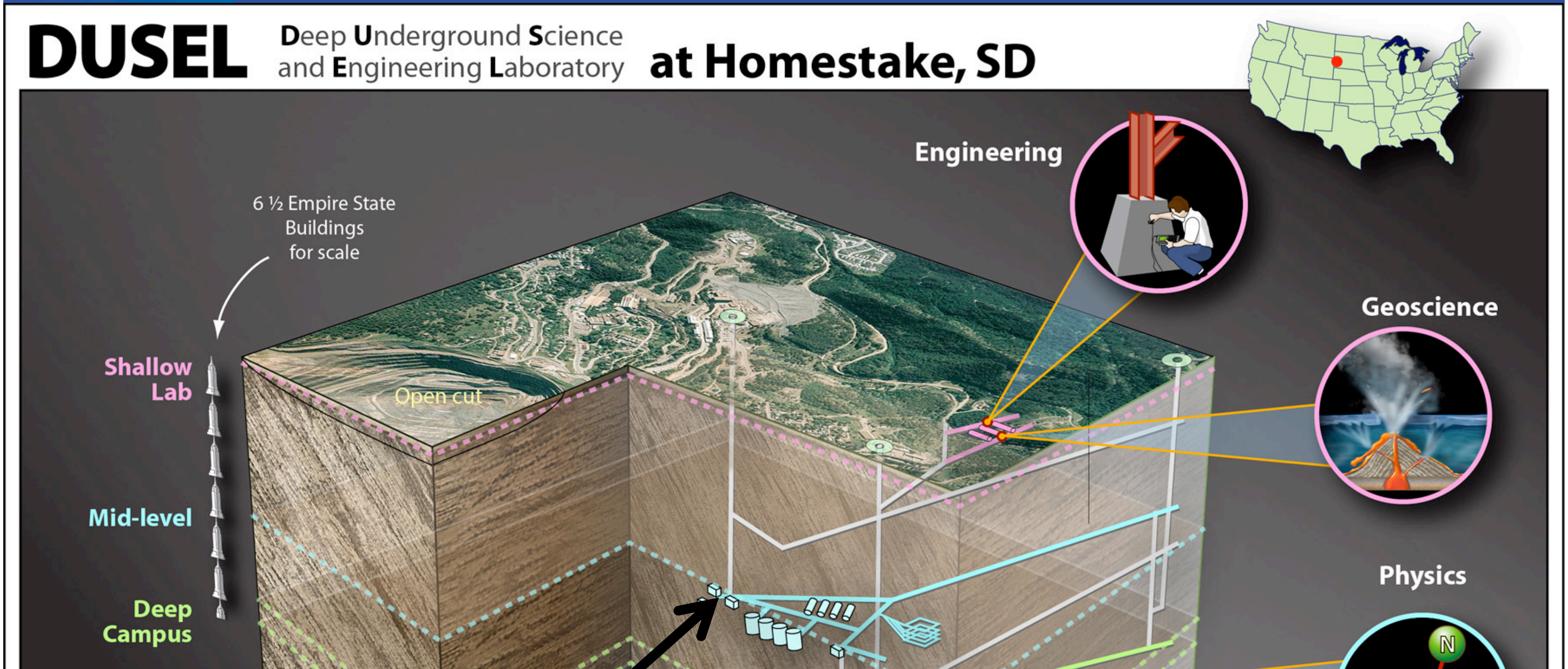
Project X

Neutrinos
Muons
Kaons
Nuclei

"simultaneouly"



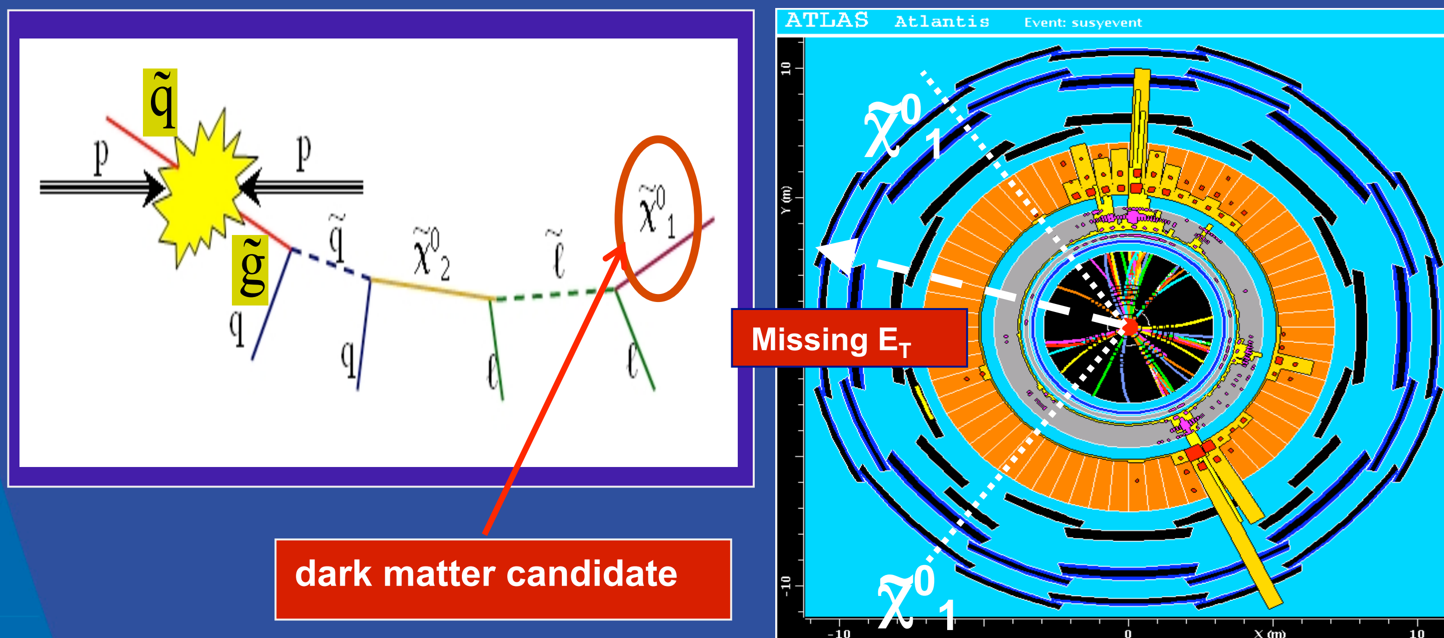




Ray Davis's Experiment

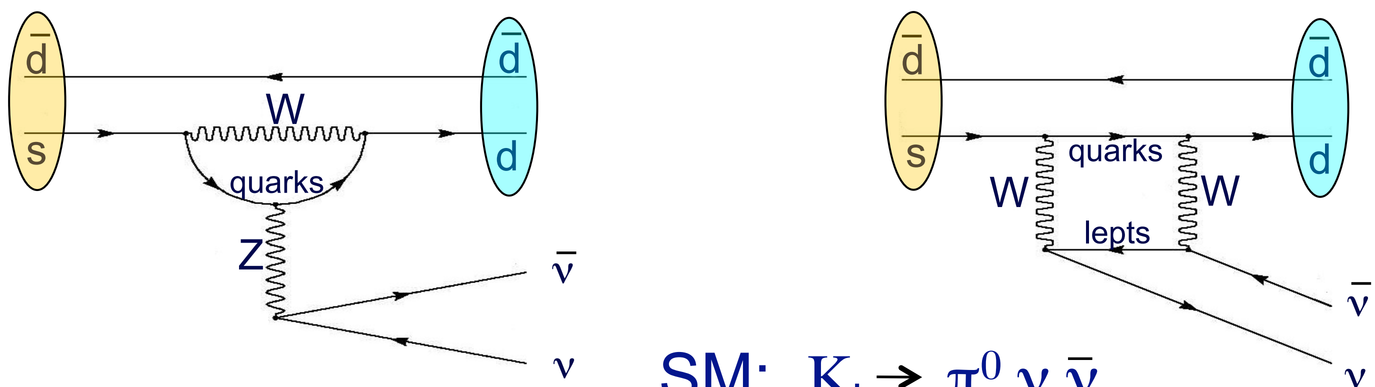
More LHC/Intensity frontier

- ATLAS/CMS discovers strongly coupled SUSY

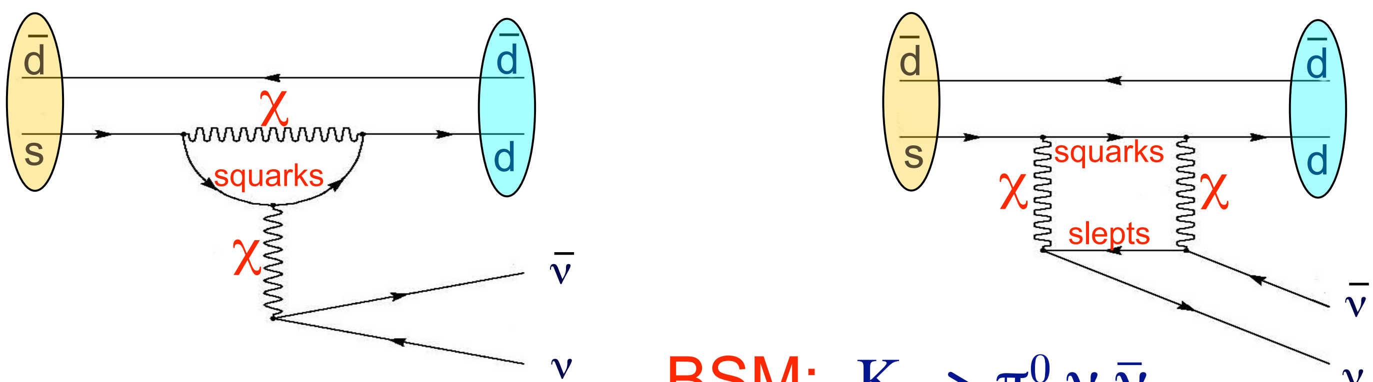


- A host of new particles: fit roughly some masses, make assumption on couplings

Large effects in kaon decay rates



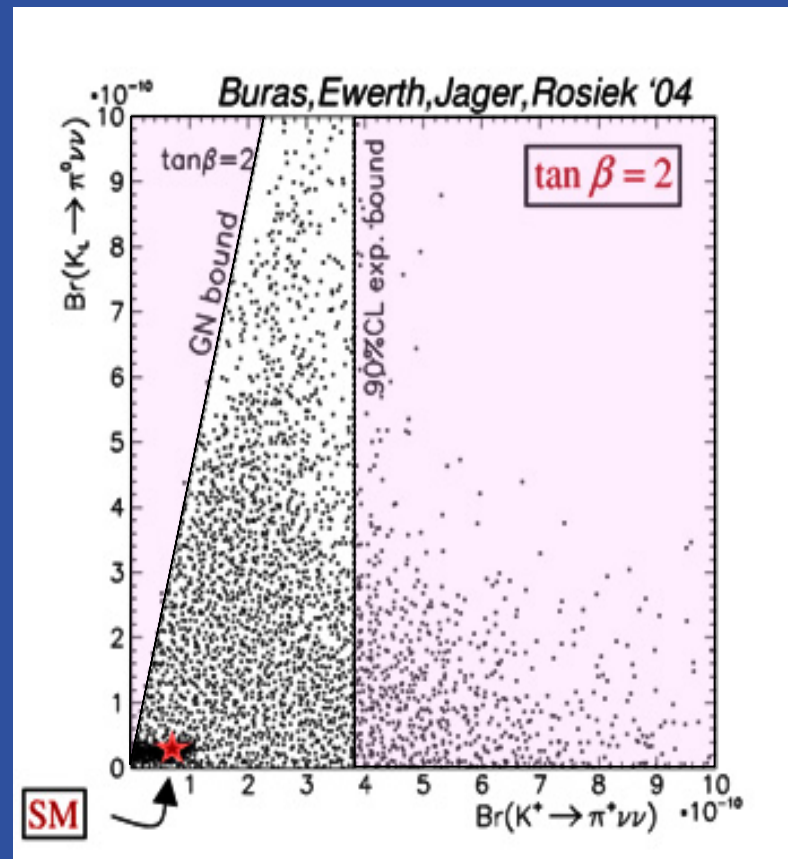
SM: $K_L \rightarrow \pi^0 \nu \bar{\nu}$



BSM: $K_L \rightarrow \pi^0 \nu \bar{\nu}$

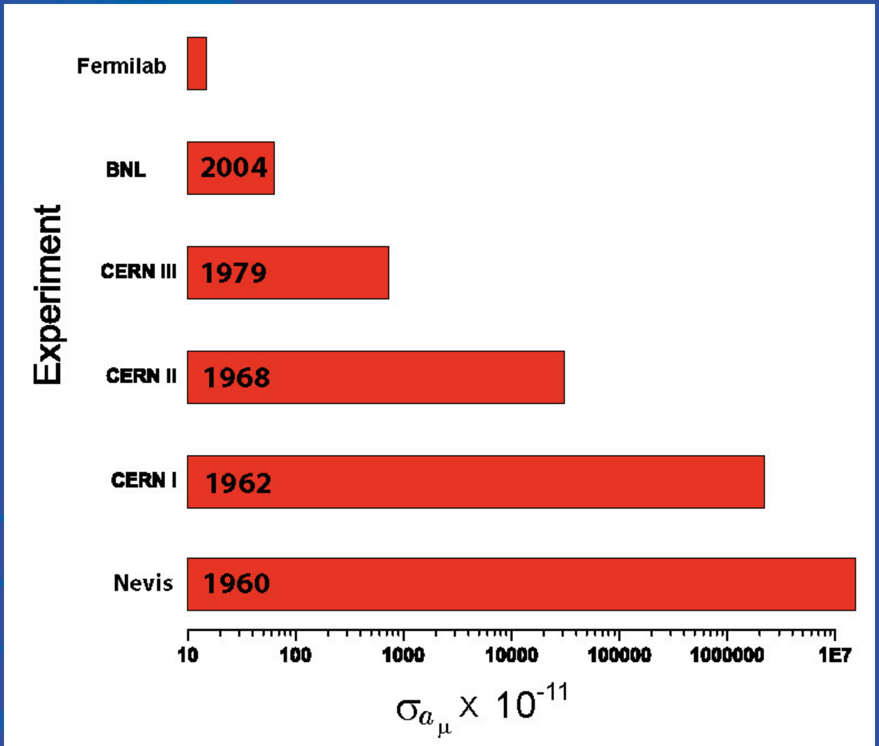
For particular classes of SUSY

Decay	Branching Ratio ($\times 10^{10}$)	
	Theory (SM)	Experiment
$K^+ \to \pi^+ \nu\bar{\nu}(\gamma)$	0.85 ± 0.07[1]	$1.73^{+1.15}_{-1.05}$[2]
$K_L^0 \to \pi^0 \nu\bar{\nu}$	0.28 ± 0.04[3]	< 670 (90% CL)[4]

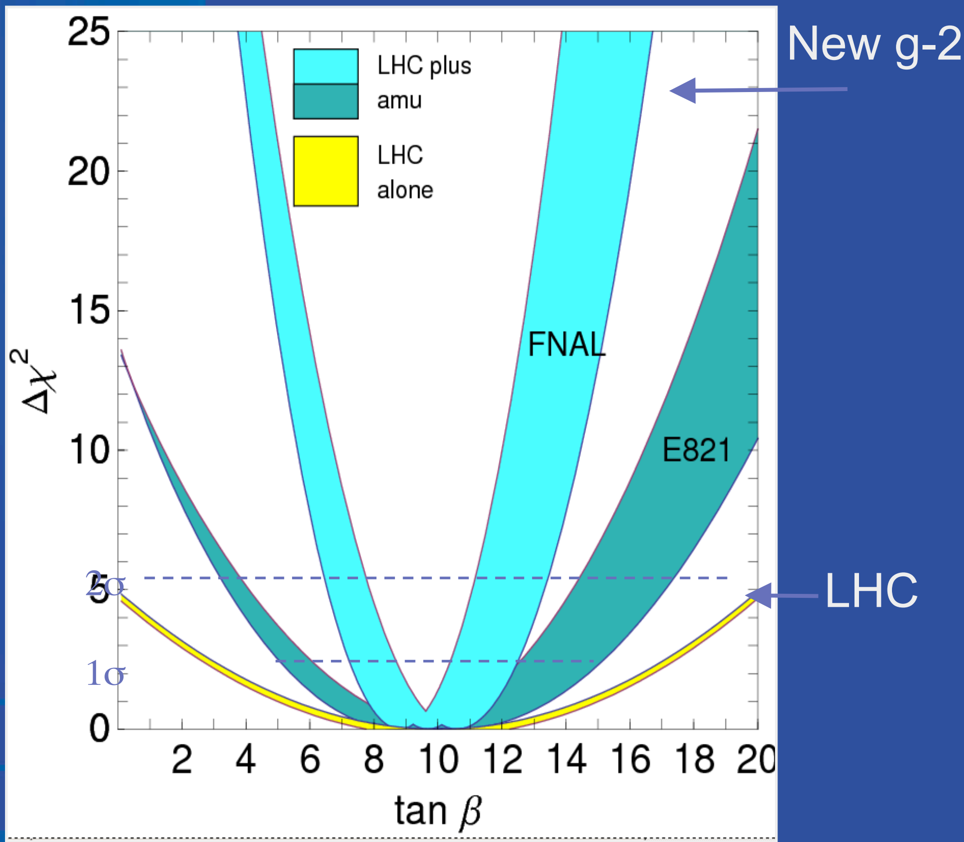


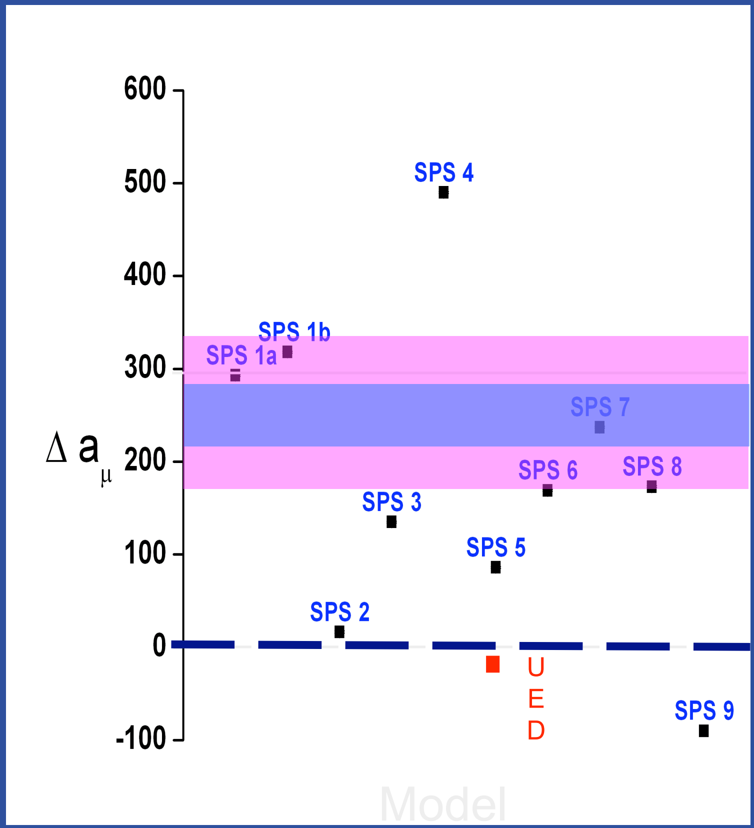
- Large effect on rare K decay modes highly suppressed with SM particles
- Much higher SM backgrounds in B and C decays
- (See also Neubert at BF2010)

A new (g-2) to error of $0.14{*}10^{-11}$

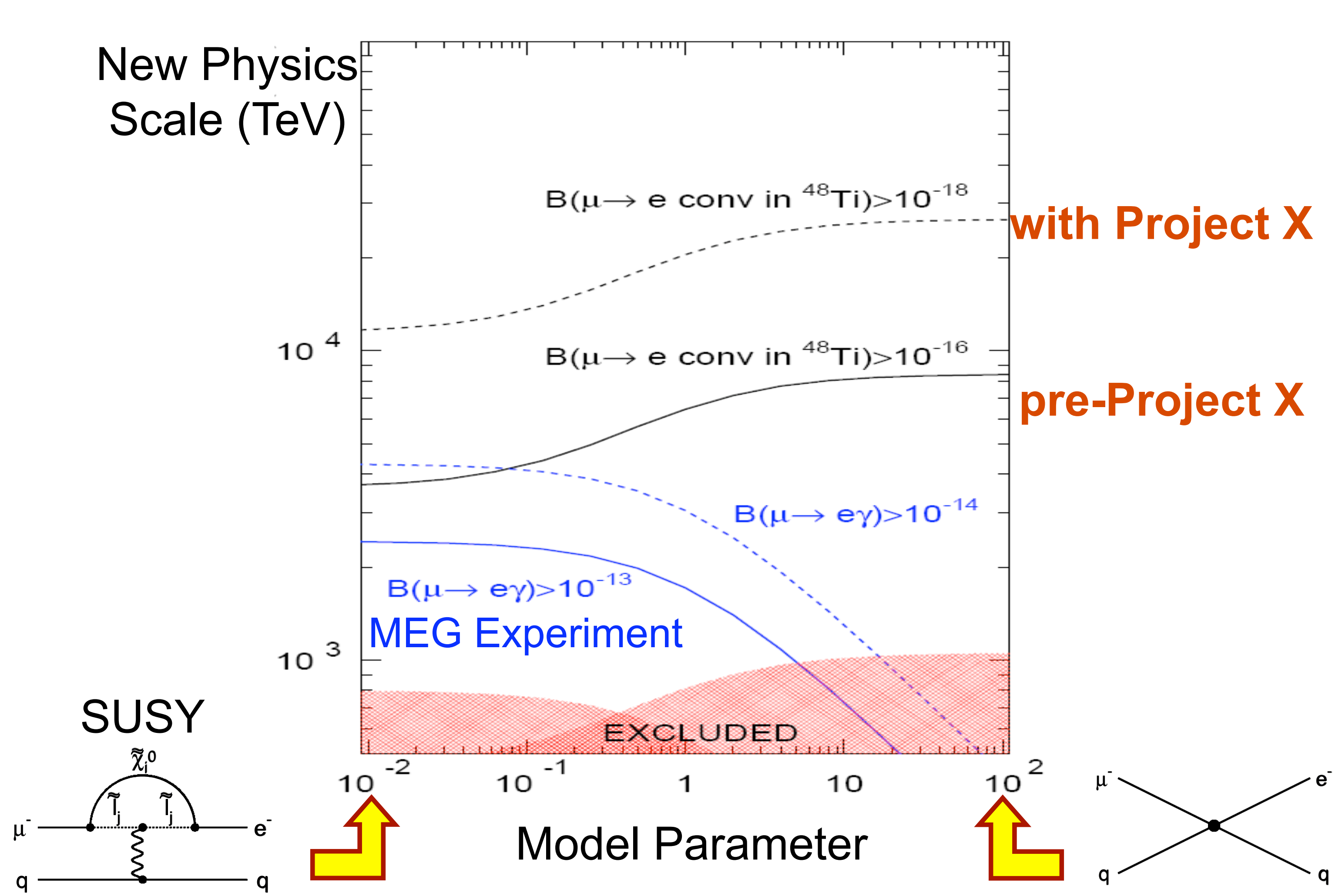


A new (g-2) to $0.14 * 10^{-11}$





Mu2e can probe $10^3 – 10^4$ TeV



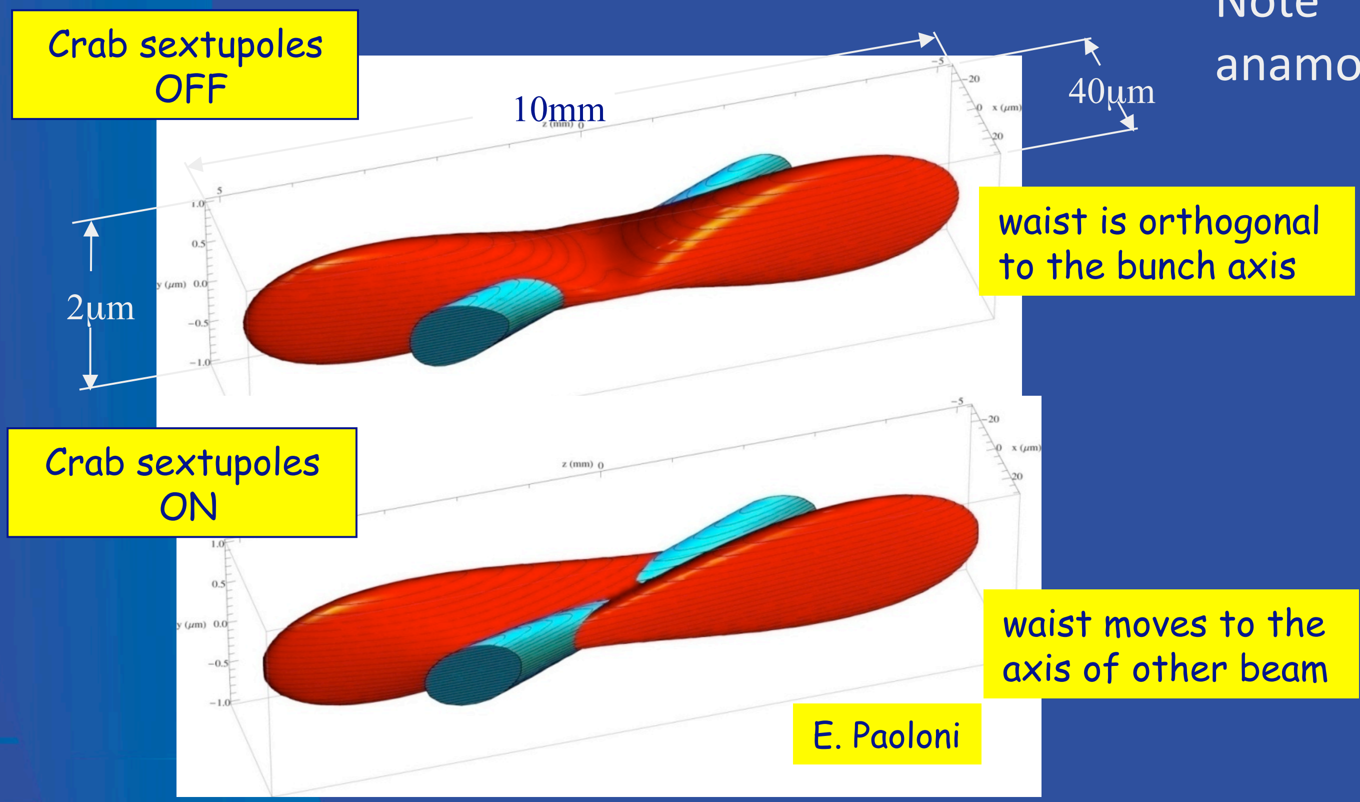
Fermilab

At the intensity frontier: Super B

- One hundred times the luminosity of existing B-factories.
- Complementary program to LHC: flavor physics will manifest discoveries at LHC as well as higher mass scales
- Unlikely to be produced with present designs due to huge power loads: go to low emittances and waist focus. The main challenge is to maintain the low emittance. Two designs one in Japan and one in Italy

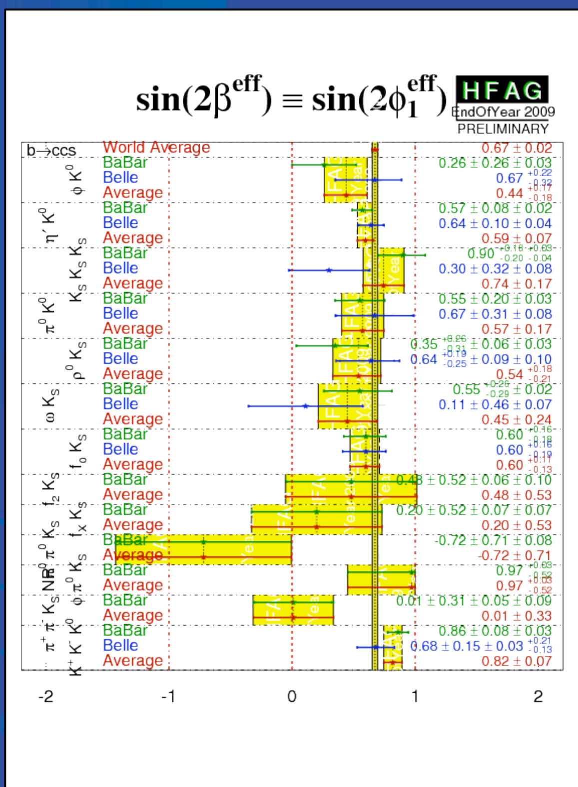
Super B: 4 Gev x 7 GeV

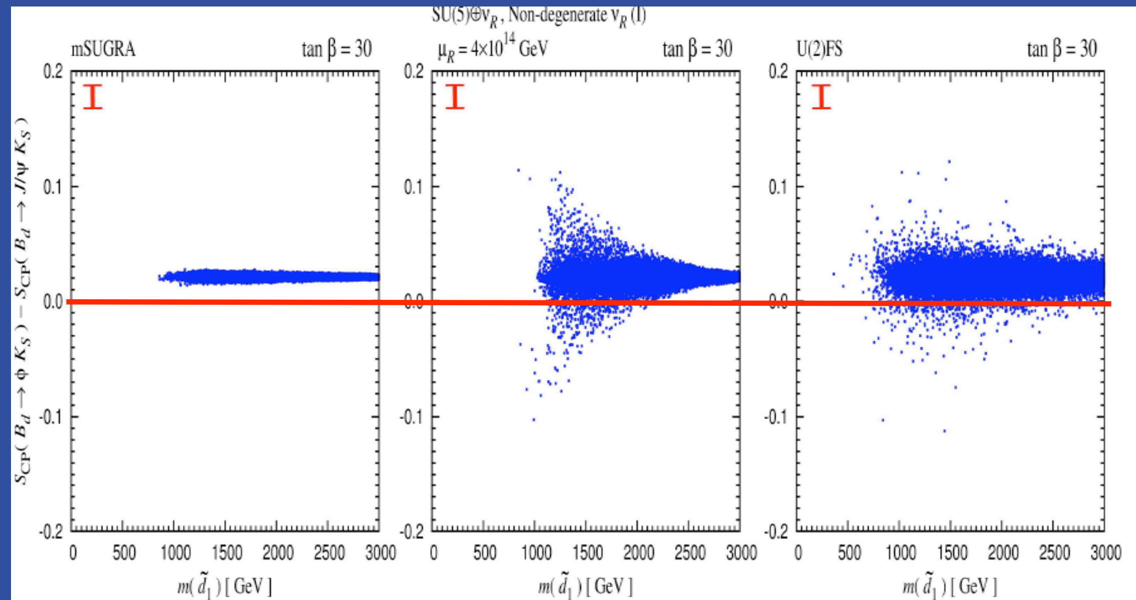
Note
anamorphic scales



With crabbed waist, all particles from both beams collide in the minimum β_y region, producing a net gain in luminosity and a broad tune plane

New physics in CPV: sin2β





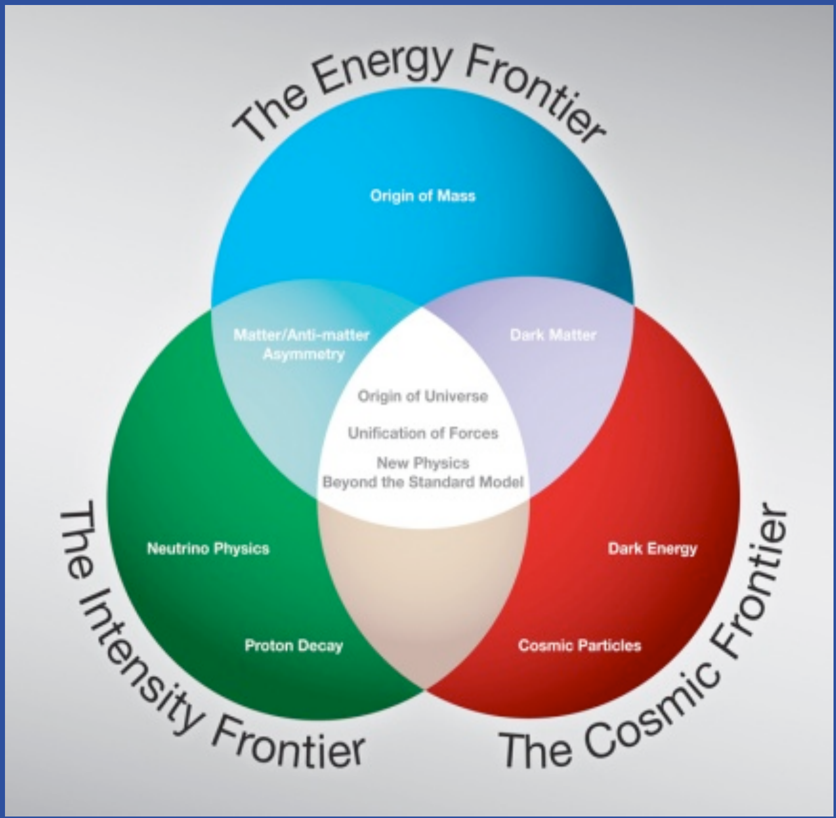
Many channels can show effects in the range Δs ~ 0.01-0.04

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$S(\phi K^0)$	0.13	0.02 (∗)
$S(\eta' K^0)$	0.05	0.01 (∗)
$S(K^0_S K^0_S K^0_S)$	0.15	0.02 (∗)
$S(K^0_S \pi^0)$	0.15	0.02 (∗)
$S(\omega K^0_S)$	0.17	0.03 (∗)
$S(f_0 K^0_S)$	0.12	0.02 (∗)

(*) theory limited

Three main thrusts

- The energy frontier: produce particles at highest energy
- The intensity frontier: the most particles for neutrinos and rare decays
- Cosmic frontier: study phenomena in nature



In conclusion: the next decade…..

Chaos ~~or~~ illumination

Chaos and illumination